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Body sway after-effects following voluntary intermittent light finger touch

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Effects of light touch on body sway have usually been investigated with some form of constant contact. Only 2 studies investigated transient sway dynamics following the addition or withdrawal of light touch. This study adopted a paradigm of intermittent touch and assessed body sway during as well as following short periods of touch of varying durations to investigate whether effects and after-effects of touch differ as a function of touch duration. In a modified heel-to-toe posture, 15 blindfolded participants alternated their index finger position between no-touching and touching on a strain gauge in response to low- and high-pitched auditory cues. Five trials of 46 seconds duration were segmented into eleven sections: a 6-second no-touching period was followed by 5 pseudo-randomly ordered touching periods of 0.5-, 1-, 1.5-, 2-, and 5-second duration, each of which was followed by another 6-second no-touching interval. Consistent with previous research, compared to no-touching intervals sway was reduced during touch periods with touch durations greater than 2 seconds. Progressive reductions in sway were evident after touch onset. After touch withdrawal in the 2-second touch condition, postural sway increased and returned to baseline level nearly immediately. Interestingly, in the 5-second touch condition, reductions in sway persisted even after touch withdrawal in the medio-lateral and antero-posterior plane for around 2.5 and 5.5 seconds respectively. Our intermittent touch paradigm resulted in duration-dependent touch effects and after-effects; the latter is a novel finding and may result from a more persistent postural set involved in proactive sway control.

Keywords*:* Intermittent; Light touch; Postural sway; Standing balance; After-effects

Introduction

Lightly touching a reference object with the finger tip reduces postural sway even though the level of contact force is not sufficient to provide mechanical support [1]. It has been proposed that cutaneous afferent information from the contact provides cues that indicate own body sway [2]. Numerous studies have investigated the nature of this touch effect [3-12]. However, previous studies on the effect of light skin contact on body sway have focused on steady state contact only; except 2 [13, 14] studies have probed the time course of body sway subsequent to touch onset or withdrawal.

The postural control system reweights all available sensory channels in order to optimize the sensorimotor control of stance in altered sensory environments [15]. Gain of a sensory channel is dynamically adjusted depending on a current estimate of its reliability as a reference for own body motion [16, 17]. This dynamic function of gain adjustment is non-linear with regard to sensory perturbations [18, 19]. Fast adaptation of the postural control system to the addition or withdrawal of light touch is critical in real life situations, as we may face intermittent availability of a support such as a handrail or furniture when moving through our environment. It is therefore important to study stabilization effects and after-effects of intermittent touches with varying durations, in order to see their impacts on postural control.

Postural stabilization with finger tip tactile feedback has been shown to be a fast process. Rabin and colleagues [13] probed the time course of the light touch effect with a paradigm where finger tip light touch had to be established abruptly. They reported that upon contact body sway is exponentially reduced with a time constant of 1.6 seconds. In a more recent study, Sozzi and colleagues [14] adopted a paradigm with actively as well as passively initiated, abrupt addition or withdrawal transitions of visual or haptic afferent information. In the active transitions of haptic cues from no-touch to touch, they reported a latency of the onset of sway decrease of around 1.3 seconds with a time constant of 0.8 seconds. With regard to an after-effect following touch withdrawal, they observed a shorter latency of the onset of sway increase of just 1 second with a time constant of 0.8 seconds.

What these 2 studies above did not investigate, however, was whether the duration of touch exposure affects the dynamics of its after-effects on sway. Therefore, the aim of our current study, with an intermittent touching paradigm, was to investigate changes of body sway during as well as following short periods of touch of varying durations: 0.5, 1, 1.5, 2, and 5 seconds.

Based on previous studies [13, 14], we expected that light touch contact is required to last between 1.5 and 2 seconds before a reduction in sway will become visible. Sozzi et al. [14] documented that a finite amount of time is necessary for central integration process after transition of touch contact. During this time the touch signal has to pass through several stages of processing [20], in which the signal must be disambiguated within the specific postural context and interpreted in an egocentric frame of reference. If postural adjustments follow the force signal by approximately 300 ms [2, 21], it is reasonable to assume a period of 150-200 ms signal processing within supraspinal circuits. Based on the findings of Sozzi et al. [14], we assumed that sway would return to baseline levels following withdrawal within a time frame similar or shorter than the time required to integrate the touch signal.

Materials and Methods

Participants

Fifteen healthy adults (8 females and 7 males; average age 20.6 SD 2.64 years) gave their written informed consent, as approved by the Institutional Review Board of Chung Shan Medical University Hospital, to participate in the study. All of them were right-handed and reported no musculoskeletal and neurological abnormalities that could have influenced their standing balance.

Apparatus

A force plate (Bertec FP4550-08, USA) measured the six components of the ground reaction forces and moments to determine the medio-lateral and antero-posterior components of Centre-of-Pressure. A dual-axis strain-gauge (RMAX SN110336-1, Taiwan), which measured normal and lateral shear forces, formed the circular touch plate (5 cm diameter) with a smooth surface. In response to a high-pitched or low-pitched auditory cue, participants either made fingertip contact with the touch plate, mounted on a stand at waist level to the front right of the participants, or withdrew contact from the plate. Three infrared cameras (MotionAnalysis HAWK, USA) captured the motion of two reflective markers, one placed on the tip of participant's index finger and one on the edge of the touch plate. All signals were sampled at 100 Hz.

Procedure

Participants were asked to hold their index finger of the dominant hand above the touch plate while keeping the outstretched arm in a comfortable posture. Participants stood with bare feet in a modified heel-to-toe stance (the non-dominant heel touching the side of big toe of the dominant foot). Participants were then instructed to close their eyes, and to stand relaxed but as still as possible without speaking.

A single trial lasted for 46 seconds and consisted of a 6-second no-touching period (1st NT) followed by 5 touching periods of 0.5-, 1-, 1.5-, 2-, and 5-second duration (0.5T, 1T, 1.5T, 2T, 5T) in a pseudo-randomized order. Each of the 5 touch periods was followed by a 6-second no-touching period (2nd to 6th NT). The beginning and the end of each trial was cued separately to indicate the starting and ending of data collection.

Trials were started when participants were ready. On hearing a high-pitched tone, participants flexed their index finger at the metacarpal-phalangeal joint to initiate light finger contact. On a low–pitched tone, participants extend their index finger just above the touch plate. Practice trials familiarised participants with the experimental protocol. Participants performed 5 standing trials and were allowed to rest for 30 seconds between trials.

Data analysis and statistics

All data underwent low-pass filtering with second-order Butterworth filter and 6 Hz cut-off frequency. According to the vertical touch force detected by the strain gauge, the onset and offset of each touching period was determined. Afterwards, data were divided into bins of 500 ms duration in order to standardize the number of data points for the sway measure extraction in different duration conditions. Due to the narrow bin width, we chose to analyze sway in terms of Centre-of-Pressure velocity (dCOP) as its variability measure would be less susceptible to voluntary low frequency drift than COP position. Also, a velocity-dependent signal resembles postural control better than position or acceleration under experimental conditions of sensory manipulation [22]. The standard deviation (SD) of dCOP in the medio-lateral ($dCOP_{ml}$) and antero-posterior ($dCOP_{ap}$) directions were calculated separately for the respective bins of interest and averaged for each duration condition across each of the five trials of a participant.

Using statistical software (SPSS 18.0, Chicago, IL, USA), firstly, we examined whether the recurring light touch would result in accumulated effects across a trial despite the interruptions. The change of sway across the no-touching periods irrespective of the inserted touch duration conditions, i.e., the last 7 bins of the 1st NT and the first 7 bins of the 2nd to 6th NT, was examined by two-way ANOVA (bin x sequence). Secondly, in order to examine touch effects two-way ANOVA (transition x duration) was conducted to compare the second to last NT bin before touch onset and the last bin of each touch duration conditions (0.5T, 1T, 1.5T, 2T, and 5T). The bin just before touch onset was not chosen because during this bin the high-pitched cuing tone had occurred and the touching movement was in preparation. ANOVAs were followed up with simple contrasts to examine touch effects within each touch duration condition. Furthermore, the touch effects were fitted with linear regressions as a function of the five non-linear touch durations. Finally, for the specific duration conditions with significant touch effects, sway evolution after touch onset and withdrawal was evaluated by comparing the values of the respective touch bins with the 99% confidence interval (CI) of the first 11 bins of the 1st baseline NT. The significance level was set at 0.05.

Results

Overall, 52 out of 375 touch sections were excluded from data analysis, among which 21 had an average touch force greater than 1.4 N, 27 had an actual touch duration that deviated by more than 200 ms from the experimentally set duration (i.e., severely delayed response latencies to the auditory cue). In 4 touch sections the finger accidentally missed the contact plate when touch had to be established. The mean vertical contact forces was 0.67 N with SD 0.32 N. Delays due to participants' latencies in response to the auditory cue meant that the actual touching periods were slightly shorter or longer than the set periods. The actual duration for the conditions of 0.5T, 1T, 1.5T, 2T, and 5T were 576 ms (range 480-700), 1012 ms (range 880-1140), 1540 ms (range 1450-1680), 2041 ms (range 1980-2140), and 4992 ms (range 4870-5050) respectively. Fig. 1 represents the dCOP fluctuations and touch force components of a sample trial.

Insert Figure 1 about here

Fig. 2 illustrates SD of $dCOP_{ml}$ and of $dCOP_{ap}$ for each of the six no-touching periods irrespective of the touch duration conditions. Postural sway on the medio-lateral axis was slighter greater and more variable than on the antero-posterior axis due to the modified heel-to-toe stance. The two-way ANOVA revealed no significant main effect of bin ($dCOP_{ml}$ $F_{6,84} = 0.785$, $p = 0.512$; $dCOP_{ap}$ $F_{6,84} = 1.552$, $p = 0.227$), suggesting that the 6-second no-touching periods in between touching periods were long enough for resetting of sensory integration. No main effect of sequence ($dCOP_{ml}$ $F_{5,70} = 0.58$, $p = 0.582$; $dCOP_{ap}$ $F_{5,70} = 1.759$, $p = 0.133$) was shown, signaling no accumulated effect of the history and number of previous intermittent touch periods.

Insert Figure 2 about here

The two-way ANOVA on the touch effects in the medio-lateral plane (Fig. 3 left panel) revealed a main effect of transition ($F_{1,14} = 5.889$, $p = 0.029$, partial $\eta^2 = 0.296$). No other effects were found. The simple contrasts revealed significant touch effects for 2T ($F_{1,14} = 7.244$, $p = 0.018$, partial $\eta^2 = 0.341$) and 5T ($F_{1,14} = 5.064$, $p = 0.041$, partial $\eta^2 = 0.266$). Compared to the second to last bin in the preceding NT, postural sway in the last bin of 2T and 5T decreased by 17.5% and 18.0%, respectively. The averaged data give hint of a trend towards further sway reductions with increasing touch duration, and the linear regression fitting indicated a slope of -0.093 cm/s ($p = 0.067$, $R^2 = 0.013$).

Insert Figure 3 about here

The two-way ANOVA on the touch effects in the antero-posterior plane (Fig. 3 right panel) revealed a main effect of transition ($F_{1,14} = 9.912$, $p = 0.007$, partial $\eta^2 = 0.415$). No other effects were found. The simple contrasts revealed borderline touch effects for 2T ($F_{1,14} = 3.774$, $p = 0.072$, partial $\eta^2 = 0.212$) and significant touch effects for 5T ($F_{1,14} = 9.405$, $p = 0.008$, partial $\eta^2 = 0.402$). Compared to the second to last bin in the preceding NT, postural sway in the last bin of 2T and 5T decreased by 17.8% and 26.1%, respectively. The averaged data give hint of a trend towards further sway reductions with increasing touch duration, and the linear regression fitting indicated a slope of -0.069 cm/s ($p = 0.041$, $R^2 = 0.017$).

As for 2T and 5T touch effects and after-effects are shown for both $dCOP_{ml}$ and $dCOP_{ap}$ in Fig. 4. The evolution of sway across the respective bins is compared to the 99% CI of the baseline NT. Progressive reductions in sway were evident after touch onset (Fig. 4 left panels). Both the 2T and 5T duration conditions have decreased below the 99% CI over the time course of the 0.5- to 1.5-second bin after touch onset and both duration conditions progress in parallel to the 2-second bin after which the 2T condition ceases. After touch withdrawal (Fig. 4 right panels), we see a sudden increase in sway in the first 0.5-second bin as compared to the last bin during touch in both duration conditions. However, the gradual increase in sway does not mirror the time course of sway reduction after touch onset as the two duration conditions do not progress in parallel anymore. After touch withdrawal, in 2T postural sway increased and returned to baseline level immediately in the medio-lateral plane and after 0.5 second in the antero-posterior plane. Interestingly, in 5T sway had returned to baseline level for the 3-, 4- and 4.5-second bins after touch withdrawal but dropped below baseline at the 5.5-second bin in the medio-lateral plane. In the antero-posterior plane in 5T, sway remained below baseline except for the 3-second bin. Bonferroni-corrected directed-hypothesis post-hoc single comparisons for the 2T and 5T conditions ($\alpha<0.0045$; 0.1/22=0.0045) indicated that for 5T exclusively were bins significantly below baseline: in the medio-lateral plane the 2-second bin and in the antero-posterior plane the 0.5- and 1-second bins.

Insert Figure 4 about here

Discussion

Up to now, only 2 studies [13, 14] assessed the transient response of light touch on the control of body sway by adopting a paradigm of abrupt addition or withdrawal of haptic information of long durations. In our present study, using an intermittent touching paradigm, we examined how a train of short duration light touch periods alters sway. Our results show progressive reductions in sway after touch onset in the 2T and 5T duration conditions, following an exponential decrease reaching asymptote within 2-3 seconds after onset and thus are in good accordance with the exponential decay functions previously reported [13, 14]. Postural sway decreased to lower than 99% CI of baseline no-touching intervals after 0.5 to 1 second after touch onset. At the final bin, sway reductions amounted to 17.5-17.8% with exposure duration of 2 seconds (actual range 1980-2140ms) and by 18.0-26.1% with exposure duration of 5 seconds (actual range 4870-5050ms).

Inconsistent with our prediction, the time course of sway increase after touch withdrawal did not mirror the inverted sway reduction following touch onset. Sway did not return to baseline levels within the same time frame but after-effects were shown for the 5T condition, which lasted for up to 5.5 seconds in contrast to the 0.5 to 1 second period observed for sway reduction after integration of touch information. As a qualitative observation, only 5T showed bins that were significantly below baseline after Bonferroni-correction. This suggests that the reduction in sway with light touch does not depend on the constant presence of a haptic force signal but can be upheld for an additional amount of time. This finding is in contrast to the report of Sozzi and colleagues [14] who observed a shorter duration of sway increase after touch withdrawal compared to sway reduction after touch onset. We believe that this discrepancy rests on differences in the adopted paradigms, i.e. train of intermittent short touch durations versus touch section with durations of 30 seconds and longer.

These results express two interesting insights with respect to the 5T condition. The first is that the 2-second duration, although effective in reducing sway, is not of sufficient duration to induce touch after-effects. That the after-effects occur in the 5-second duration could due to the postural control system requiring up to 5 seconds for establishing a postural set adjusted to the requirements of light touch contact. The second insight is perhaps, that this light touch postural set is kept online depending on the context of the sensorimotor task. Knowing that a period of light touch will be followed by a long no contact interval as in the study by Sozzi et al. [14] might lead to a rapid taking offline of the light touch postural set in order to optimize sensorimotor gains in contrast to the expectancy that it will be still required in the immediate future as in our intermittent touch paradigm.

Dealing with intermittent touch intervals might result in the postural control system to adopt a more conservative sensorimotor control strategy for an intermediate time frame with the consequence of persisting lowered sensorimotor gain for the other sensory channels involved in standing balance (i.e., vestibular, plantar somatosensory and muscle proprioceptive afferences). For example, Jeka et al. [23] demonstrated faster down-weighting and slower up-weighting of the gain of the visual channel in response to transient changes in amplitude of a wide-field oscillatory visual motion stimulus. They interpreted the longer duration of up-weighting the visual channel as a conservative postural control strategy when confronted with a sensory environment featuring regular transient changes.

On the other hand, it does not appear that participants chose constant multimodal sensory gains across an entire trial as sway in the no contact periods did differ as a function of the preceding touch duration. This means that any subsequent trains of touch durations shorter than 5 seconds, interrupting the no touch periods of 6-second duration, were not considered sufficiently informative in terms of touch feedback utilization and thus did not suggest sustained sensory gain settings. It is also possible that continuous tactile exploration, e.g. 5-second continuous light touch, leads to enhanced cortical excitability [24], and hence its touch effects may last after touch withdrawal during which the enhanced cortical excitability is still maintained. Another mechanism that may account for the after-effects is the constraining effect brought about by the suprapostural touch task. Keeping the contact finger just above the touch plate and ready for establishing the next touch period may itself form a precision task superordinate to the control of sway leading to decreased sway by active sway constraining in the absence of finger tip force feedback [25].

That intermittent touch effects did not accumulate across a trial suggests that the 6-second no-touching intervals between intermittent touches were sufficient for a wash-out and therefore do not cause difficulties when investigating the effects of intermittent touch. Furthermore, the experimental conditions of 5 different touch durations were performed in random order, and our findings suggested a linear trend towards further sway reductions with increasing touch duration. Therefore, we believe that our findings of the positive postural stabilization effects of intermittent touch would remain if a longer no-touching interval were adopted. However, our study design was limited by the lack of touch duration between 2 and 5 seconds. Based on our results, future studies might focus on touch durations within but also beyond this range. Further, a systematic variation of the durations of the inter-touch no contact periods will be important to shed more light on the occurrence of longer-duration touch after-effects following touch withdrawal.

A specific aspect of our experimental setup was that the surface of the contact plate was relatively smooth. One could argue that the low friction resulted in exceptionally low shear forces and a reduces tactile sensation at the fingertip and therefore somehow affected our results. Jeka and Lackner [26] demonstrated, however, that the light touch effect on sway is not dependent on the contact surface having rough or smooth characteristics.

In conclusion, our new intermittent touch paradigm not only confirms the postural stabilization effects of touch, but also revealed touch after-effects. The postural stabilization effects provided by light touch have been demonstrated on pathological populations who suffered from postural instability due to various etiologies [3-11]. There is a proposition that the paradigm of light finger touch may represent a potential treatment for patients suffering from postural instability [3, 8], probably as a sensory prosthesis or due to exercise-related benefits. Our findings of postural stabilization effects during and after intermittent touch provide further insights into this potential treatment paradigm, which may be especially important for patients who are weaning from constant touch during balance retraining.

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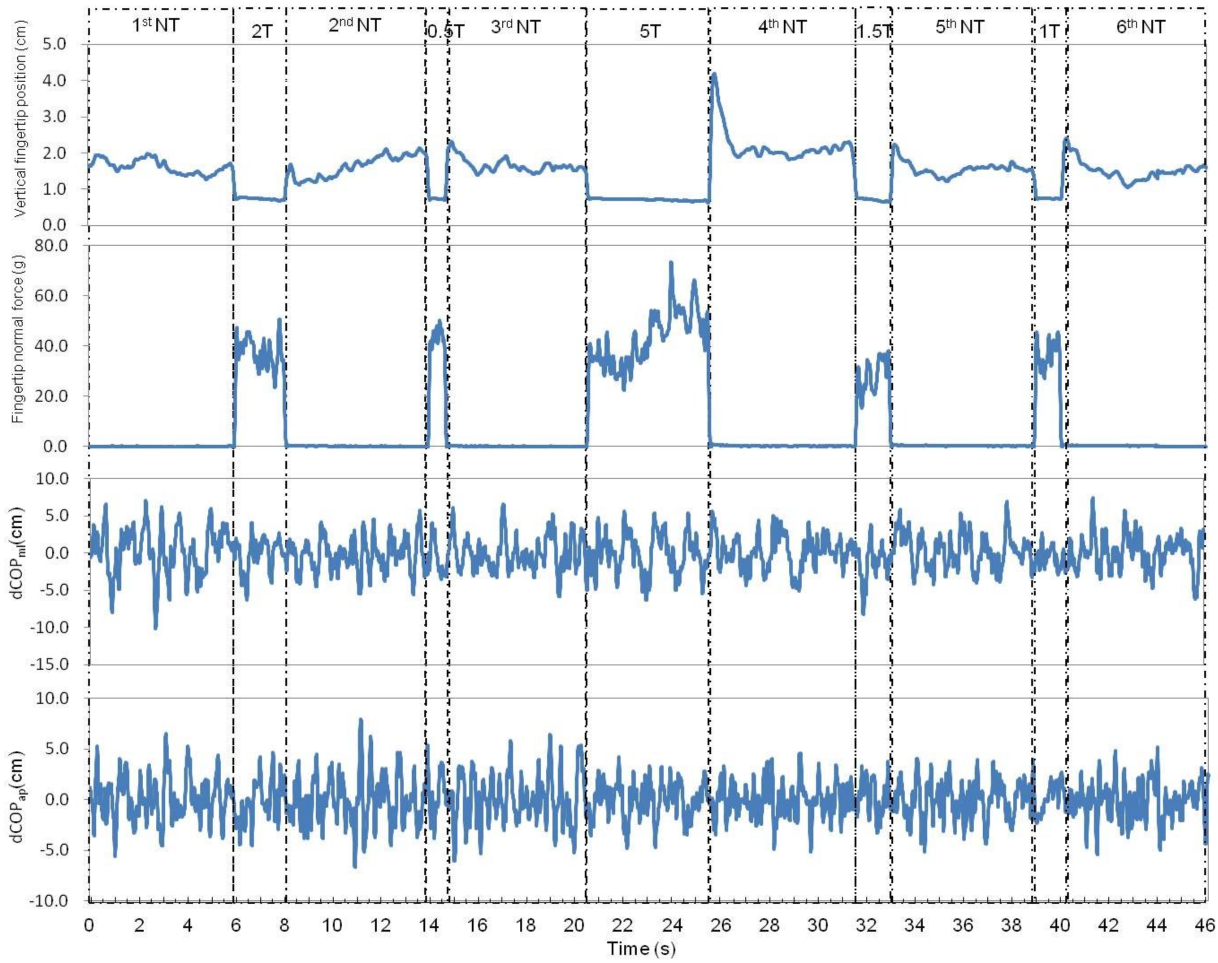
Figure legends.

Fig. 1. A representative trial showing vertical fingertip position, fingertip normal force, and Centre-of-Pressure velocity in the medio-lateral ($dCOP_{ml}$) and antero-posterior plane ($dCOP_{ap}$) during 46 seconds. The 46-second trial was consisted of five touching periods of 0.5-, 1-, 1.5-, 2-, and 5-second (0.5T, 1T, 1.5T, 2T, 5T) running in pseudo-random order, and six 6-second no-touching periods in between (NT).

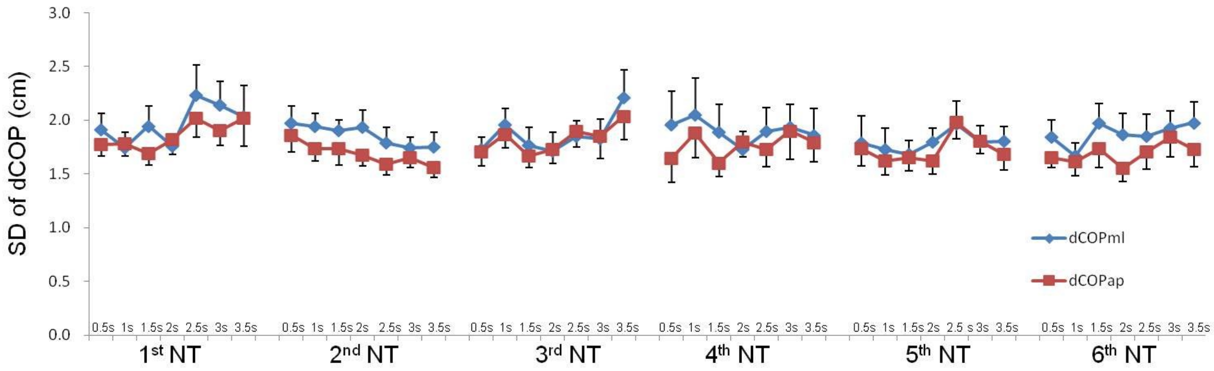
Fig. 2. The mean and between-subject SE of SD of $dCOP_{ml}$ and of $dCOP_{ap}$ as a function of sequence during no-touching periods, i.e., the last 7 bins of the 1st NT and the first 7 bins of the 2nd to 6th NT periods.

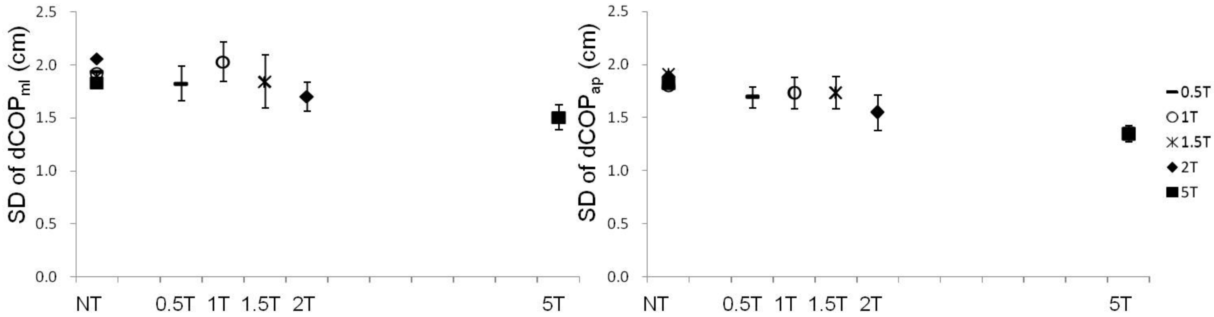
Fig. 3. The transition of SD of $dCOP_{ml}$ (left panel) and of $dCOP_{ap}$ (right panel) from no-touching (the second to last bin just before touch onset) to the steady state of touching (the last bin of each touching condition).

Fig. 4. The changes of SD of $dCOP_{ml}$ (upper panel) and of $dCOP_{ap}$ (lower panel) across the 500 ms bins after touch onset (left panel) and withdrawal (right panel) for the 2T and 5T conditions. The gray areas indicate 99% CI of postural sway during baseline no-touching interval. Between-subject SE bars are shown.

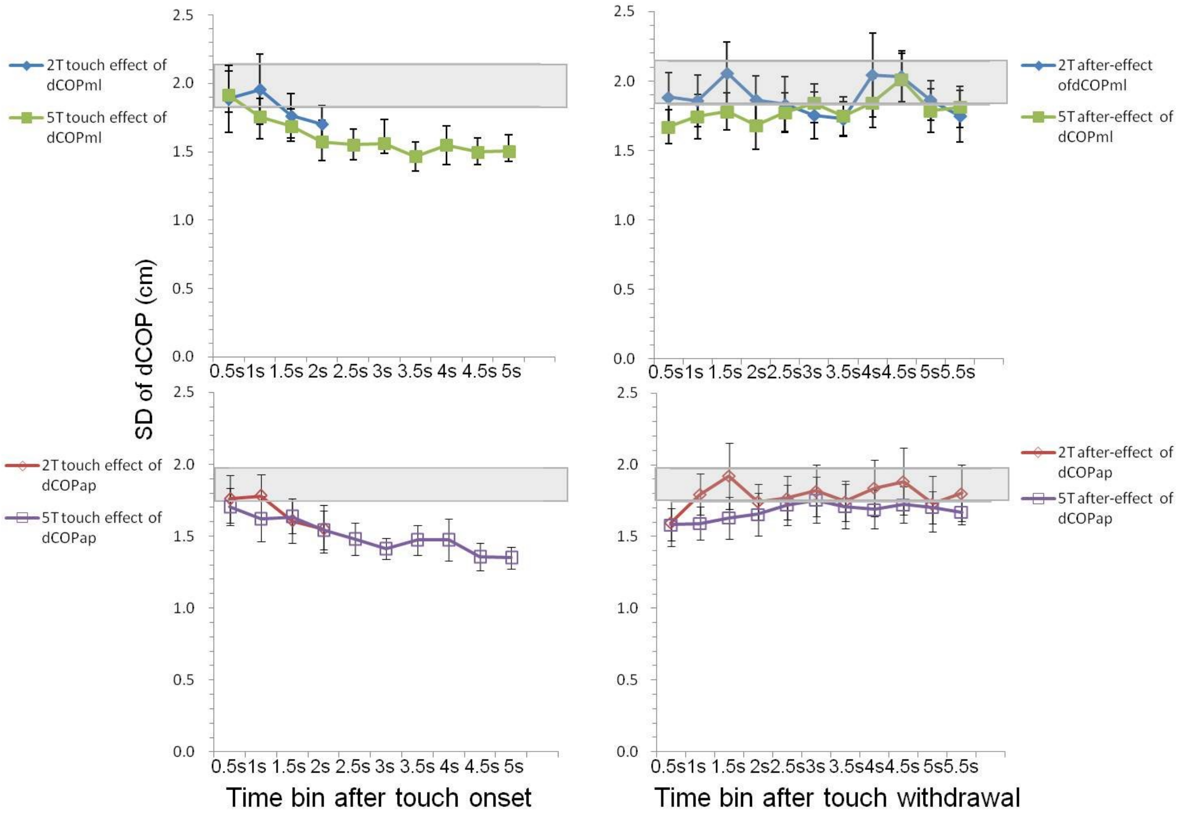


1st NT
2T
2nd NT
0.5T
3rd NT
5T
4th NT
1.5T
5th NT
1T
6th NT
Vertical fingertip position (cm)
Fingertip normal force (g)
dCOP$_{ml}$(cm)
dCOP$_{ap}$(cm)
Time (s)


SD of dCOP (cm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.5s 1s 1.5s 2s 2.5s 3s 3.5s
1st NT
2nd NT
3rd NT
4th NT
5th NT
6th NT
dCOPml
dCOPap



SD of dCOP$_{ml}$ (cm)
2.5
2.0
1.5
1.0
0.5
0.0
NT
0.5T
1T
1.5T
2T
5T
SD of dCOP$_{ap}$ (cm)
0.5T
1T
1.5T
2T
5T


2T touch effect of dCOPml
5T touch effect of dCOPml
2T after-effect ofdCOPml
5T after-effect of dCOPml
2T touch effect of dCOPap
5T touch effect of dCOPap
2T after-effect of dCOPap
5T after-effect of dCOPap
SD of dCOP (cm)
0.0
0.5
1.0
1.5
2.0
2.5
0.5s 1s 1.5s 2s 2.5s 3s 3.5s 4s 4.5s 5s
0.5s 1s 1.5s 2s 2.5s 3s 3.5s 4s 4.5s 5s 5.5s
Time bin after touch onset
Time bin after touch withdrawal

Research Highlights

1. We study after-effects with a train of 5 intermittent touches of various durations.
2. Progressive reduction in sway is evident after onset of 2- and 5-second touches.
3. Postural sway after touch withdrawal did not mirror its reduction after touch onset.
4. The touch after-effects last for 5.5 seconds after withdrawal of 5-second touch.
5. Intermittent touch may result in a more persistent postural set of proactive control.

Conflicts of interest

None.

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